

(INVEST White paper)

MOHOLE proposal for understanding the role of water in magmatic processes of oceanic ridges

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Abstract

Drilling through the whole section of oceanic crust into the upper mantle (Mohole) is the most prioritized target of scientific drilling in the second phase of IODP. Here I note the importance of the coring, sampling and analyzing the whole section of oceanic crust and the uppermost mantle, and comment on the possible implications of the role of water in quantitative modeling magmatic processes at oceanic ridges. Observation and analyses of cores would be relevant to the following issues: 1. Role of water in the mantle flow and generation of magmas beneath oceanic ridges, 2. Magma-hydrothermally altered crust interaction in the chamber, dike and sheet within the oceanic crust, 3. Magma-water interaction during eruption and emplacement of magmas at oceanic ridges.

Following observations and analyses of the MOHOLE cores would be crucial; 1. H₂O contents and fabric analyses of olivine in the upper mantle peridotite, 2. Detailed geochronology and petrography of the mid-crustal cores to understand the temporal variation of the magma flux, which may control the variation of hydrothermal circulation in the crust, and 3. Analyses of Chlorine in the extruded samples to evaluate the sea-water-induced cooling of the lavas during emplacement.

1. Introduction

Although the initial Mohole project in 1959 to drill down to the Mohorovicic discontinuity reached only the upper veneer of the oceanic crust, its concept has been the most prioritized motivation of oceanic drilling for more than half a century. The technological developments through the experiences of DSDP and ODP have enabled to construct the riser-drilling vessel Chikyu, and its operation and development are now implemented under IODP. In the second phase (2013-2023) of IODP, we should concentrate our efforts to practice the 21st Century MOHOLE, because of its scientific and social impacts. Followings are some of the ideas specifically aimed at obtaining new pictures of the oceanic crust formation at oceanic ridges.

2. Water and fabric analyses of cores from the upper mantle

Last decades have seen the development of mineral chemistry arguments concerning the role of water in the physical properties and segregation processes in the upper mantle. Hirth and Kohlstadt (1996), Karato and Jung (1998) have argued that partial melting may occur deep below the oceanic ridges (>100km depth), and extraction of water from olivine to the partial melt may increase viscosity and compressional wave velocity of the bulk peridotite, which may result in the formation of rigid lithosphere in the oceanic areas. Stress distribution in the corner flow beneath oceanic ridge may have implications for the lattice-preferred orientation of olivine and shear localization and melt concentration just beneath the oceanic ridge (Katz et al., 2006). The former is relevant to seismic anisotropy of the upper mantle of oceanic areas. Recent experimental works have elaborated the important role of water in the lattice-preferred orientation of olivine in various stress conditions (e.g., Jung and Karato, 2001). Katayama et al., (2004) experimentally showed that under low stress and medium water content conditions, E-type fabric of olivine predominates, which fits the observation in the oceanic upper mantle in terms of small V_{SH}/V_{SV} ratio and strong shear-wave splitting.

On the other hand, water contents of the source peridotite could be evaluated from the glass composition of MORBs. Saar et al. (2002) analyzed volatile-undersaturated glass inclusions in phenocrysts of MORBs and constrained the volatile abundances of the source rocks together with the evaluation of role of seawater contamination and degassing. Hauri et al. (2006) experimentally determined the partitioning of water among nominally dry minerals and melts, and constrained the possible water contents of the upper mantle materials.

MOHOLE may give rare opportunity to analyze the water contents of olivine and other nominally dry minerals and fabric analyses of olivine in the intact section of the upper mantle, which are crucial in modeling the corner flow of the upper mantle peridotite. Although even recent quantitative 1-D modeling of oceanic ridges does not always take the role of water on physical properties and fabric of peridotite into consideration (e.g., Rabinowicz and Toplis, 2009), these parameters are important, and should be quantitatively evaluated in the IODP MOHOLE cores, and should be utilized in the next generation modeling.

3. Detailed geochronology of the mid-crustal cores

Hydrothermal circulations in the oceanic crust near the ridges are important in determining geochemical budget as well as constraining the thermal histories of the oceanic crust (Rubin and Sinton, 2007). Magmatic activity often shows waxing and waning stages of various amplitudes as well as lateral variation along oceanic ridges (Delaney et al., 1998; Umino et al., 2003; Bergmanis et al., 2007; White et al., 2009). In a waxing stage, hydrothermal activity may be restricted in the upper part of the oceanic crust, whereas hydrothermal circulation may deepen and proceed in the crust in waning

magmatic stages. Interaction between magma and hydrothermally altered oceanic crust may affect the chemical composition of MORBs. Zircon geochronology and petrographic examination may determine when and how the hydrothermal activity occurred in the mid-depth oceanic crust.

4. Analyses of chlorine in the upper crustal cores

Rapid development of high-resolution monitoring of ocean floor in the last decade has enabled to decipher the detailed mode of construction of the upper oceanic crust by accumulation of lava flows along mid-ocean ridges. Soule et al. (2005) demonstrated that channelized lava flows of 10-50 meters wide and 50-500 meters long with thickness more than several meters are the main component or building block of the upper oceanic crust along the fast-spreading EPR at 9N. They also suggested high effusion rate of the order of $10^3 \text{ m}^3/\text{s}$ by model calculation assuming the rheological properties of the lava. Modeling of lava flows in subaqueous or subareal conditions has a long history of research, and includes both analytical (e.g., Hulme, 1974; Tallarico and Dragoni, 1999) and numerical FEM studies (e.g., Harris and Rowland, 2001; Hidaka et al., 2005). The choice of the rheological properties of magmas in these models is rather empirical and requires more sophisticated parameterization to understand further the physical processes occurring during lava flow emplacement (e.g., Sato et al., 2009). Especially important is the role of water-magma interaction to cool the lava interior. Perfit et al. (2003) observed large void with various hydrothermal products beneath the upper chilled crust of sheet flows, and indicated that bubbles of vaporized sea water often rise through the base of lava flows and collect beneath the chilled upper crust. Because numerical modeling often meet the difficulty of cooling lava flows during emplacement, it is important to quantitatively evaluate the effect of sea water incorporation on the cooling of the lava flows. Textural characterization of the cores, presence of alteration minerals by magma-sea water interaction in the core samples would be strongly requested.

References

- Bergmanis, EC, Sinton, J., Rubin, KH (2007) Recent eruptive history and magma reservoir dynamics on the southern East Pacific rise at 17°30'S. *Geochemistry, Geophysics, Geosystems*, 8, doi:10.1029/2007GC001742.
- Delaney, JR, Kelley, DS, Lilley, MD, Butterfield, DA, Baross, JA, Wilcock, WSD, Embley, RW, Summit, M. (1998) The quantum event of oceanic crustal accretion: impacts of diking at mid-ocean ridges. *Science*, 281, 222-230.
- Harris, AJL, Rowland, SK (2001) FLOWGO: a kinematic thermo-rheological model for lava flowing in a channel. *Bull. Volcanol.*, 63, 20-44.
- Hauri, EH, Gaetani, GA, Green, TH (2006) Partitioning of water during melting of the earth's upper mantle at H₂O-undersaturated conditions. *Earth Plan. Sci. Lett.*, 248, 715-734.
- Hidaka, M., Goto, A., Umino, S., Fujita, E. (2005) VTFS project: development of the lava flow simulation code LavaSIM

- with a model for three-dimensional convection, spreading, and solidification. *Geochemistry, Geophysics Geosystems*, 6, doi:10.1029/2004GC000869.
- Hirth, G, Kohlstedt, DL (1996) Water in the oceanic upper mantle: implications for rheology, melt extraction and the evolution of the lithosphere. *Earth Plan. Sci. Lett.*, 144, 93-108.
- Hulme, G. (1974) The interpretation of lava flow morphology. *Geophys. J. Roy Astron. Soc.*, 39, 361-383.
- Karato, S, Jung, H. (1998) Water, partial melting and the origin of the seismic low velocity and high attenuation zone in the upper mantle. *Earth Plan. Sci. Lett.*, 157, 193-207.
- Katayama, I., Jung, H, Karato, SI (2004) New type of olivine fabric from deformation experiments at modest water content and low stress. *Geology*, 32, 1045-1048.
- Katz, RF, Spiegelman, M., Holtzman, B (2006) The dynamics of melt and shear localization in partially molten aggregates. *Nature*, 442, 676-679.
- Perfit, MR. et al. (2003) Interaction of sea water and lava during submarine eruptions at mid-ocean ridges. *Nature*, 426, 62-65.
- Rabinowicz, M, Toplis, MJ (2009) Melt segregation in the lower part of the partially molten mantle zone beneath an oceanic spreading centre: numerical modeling of the combined effects of shear segregation and compaction. *J. Petrol.*, 50, 1071-1106.
- Rubin, KH, Sinton, JM (2007) Inference on mid-ocean ridge thermal and magmatic structure from MORB compositions. *Earth Plan. Sci. Lett.*, 260, 257-276.
- Saal, AE, Hauri, EH, Langmuir, CH, Perfit, MR. (2002) Vapour undersaturation in primitive mid-ocean-ridge basalt and the volatile content of earth's upper mantle. *Nature*, 619, 451-455.
- Sato, H., Nakamura, H, Ishibashi, H. (2009) One atmosphere viscosity measurements of MORBs from ODP Leg 206, Hole 1256D. Abstract submitted to the 2009 Fall meeting, American Geophysical Union.
- Soule, SA, Fornari, DJ, Perfit, MR., Tivey, MA, Ridley, WI, Schouten, H. (2005) Channelized lava flows at the East Pacific rise crest 9-10N: The importance of off-axis lava transport in developing the architecture of young oceanic crust. *Geochemistry, Geophysics, Geosystems*, 6, doi:10.1029/2005GC000912
- Tallarico, A, Dragoni, M (1999) Viscous Newtonian laminar flow in a rectangular channel: application to Etna lava flows. *Bull Volcanol.*, 61, 40-47.
- Umino, S, Miyashita, S., Hotta, F., Adachi, Y. (2003) Along-strike variation of the sheeted dike complex in the Oman Ophiolite: insights into subaxial ridge segment structures and the magma plumbing system. *Geochemistry, Geophysics, Geosystems*, 4, doi:10.1029/2001GC000233
- White, SM, et al. (2009) Significance of widespread low effusion rate eruptions over the past two million years for delivery of magma to the overlapping spreading centers at 9 N East Pacific Rise. *Earth Plan. Sci. Lett.*, 280, 175-184.